



US009071770B2

(12) **United States Patent**  
**Tan et al.**

(10) **Patent No.:** **US 9,071,770 B2**  
(45) **Date of Patent:** **\*Jun. 30, 2015**

(54) **ARRANGEMENT FOR AND METHOD OF PROJECTING AN IMAGE WITH LINEAR SCAN LINES**

USPC ..... 348/744, 756, 781, 792, 747, 794;  
359/201.1, 202.2, 199.1, 850  
See application file for complete search history.

(75) Inventors: **Chinh Tan**, Setauket, NY (US);  
**Frederick F. Wood**, Medford, NY (US);  
**Miklos Stern**, Woodmero, NY (US)

(56) **References Cited**

**U.S. PATENT DOCUMENTS**

(73) Assignee: **Microvision, Inc.**, Redmond, WA (US)

(\*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 830 days.

This patent is subject to a terminal disclaimer.

(21) Appl. No.: **13/040,536**

(22) Filed: **Mar. 4, 2011**

(65) **Prior Publication Data**

US 2011/0164225 A1 Jul. 7, 2011

**Related U.S. Application Data**

(63) Continuation of application No. 11/440,815, filed on May 25, 2006, now Pat. No. 7,924,349, which is a continuation-in-part of application No. 10/427,528, filed on May 1, 2003, now Pat. No. 7,446,822.

(60) Provisional application No. 60/380,306, filed on May 15, 2002.

(51) **Int. Cl.**  
**H04N 9/31** (2006.01)  
**H04N 9/28** (2006.01)  
**G06F 1/16** (2006.01)

(52) **U.S. Cl.**  
CPC ..... **H04N 9/3129** (2013.01); **G06F 1/1626** (2013.01); **G06F 1/1639** (2013.01); **G06F 1/1696** (2013.01)

(58) **Field of Classification Search**

CPC ..... H04N 9/3129

4,979,030 A	12/1990	Murata
5,032,924 A	7/1991	Brown et al.
5,311,321 A	5/1994	Crowley
5,673,139 A	9/1997	Johnson
5,742,358 A	4/1998	Iijima et al.
5,822,022 A	10/1998	Deter et al.
5,864,418 A	1/1999	Allen et al.
6,018,408 A	1/2000	Hong
6,122,023 A	9/2000	Chen et al.
6,371,616 B1	4/2002	Doany et al.
6,390,627 B1	5/2002	Kuroda
6,491,395 B2	12/2002	Shirakura et al.
6,832,724 B2	12/2004	Yavid et al.
7,264,360 B2	9/2007	Hatakeyama et al.
7,446,822 B2	11/2008	Stern et al.
7,511,771 B2	3/2009	Stern et al.
2003/0076423 A1	4/2003	Dolgoft
2005/0023439 A1	2/2005	Cartlidge et al.
2005/0190419 A1	9/2005	Ishihara
2006/0029295 A1	2/2006	Wine et al.

**FOREIGN PATENT DOCUMENTS**

EP 1168231 1/2002

*Primary Examiner* — Jefferey Harold

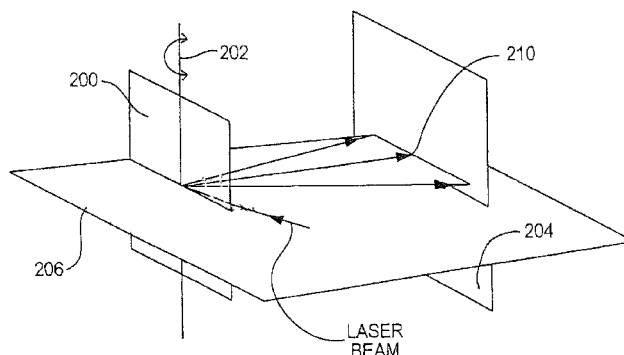
*Assistant Examiner* — Jean W Desir

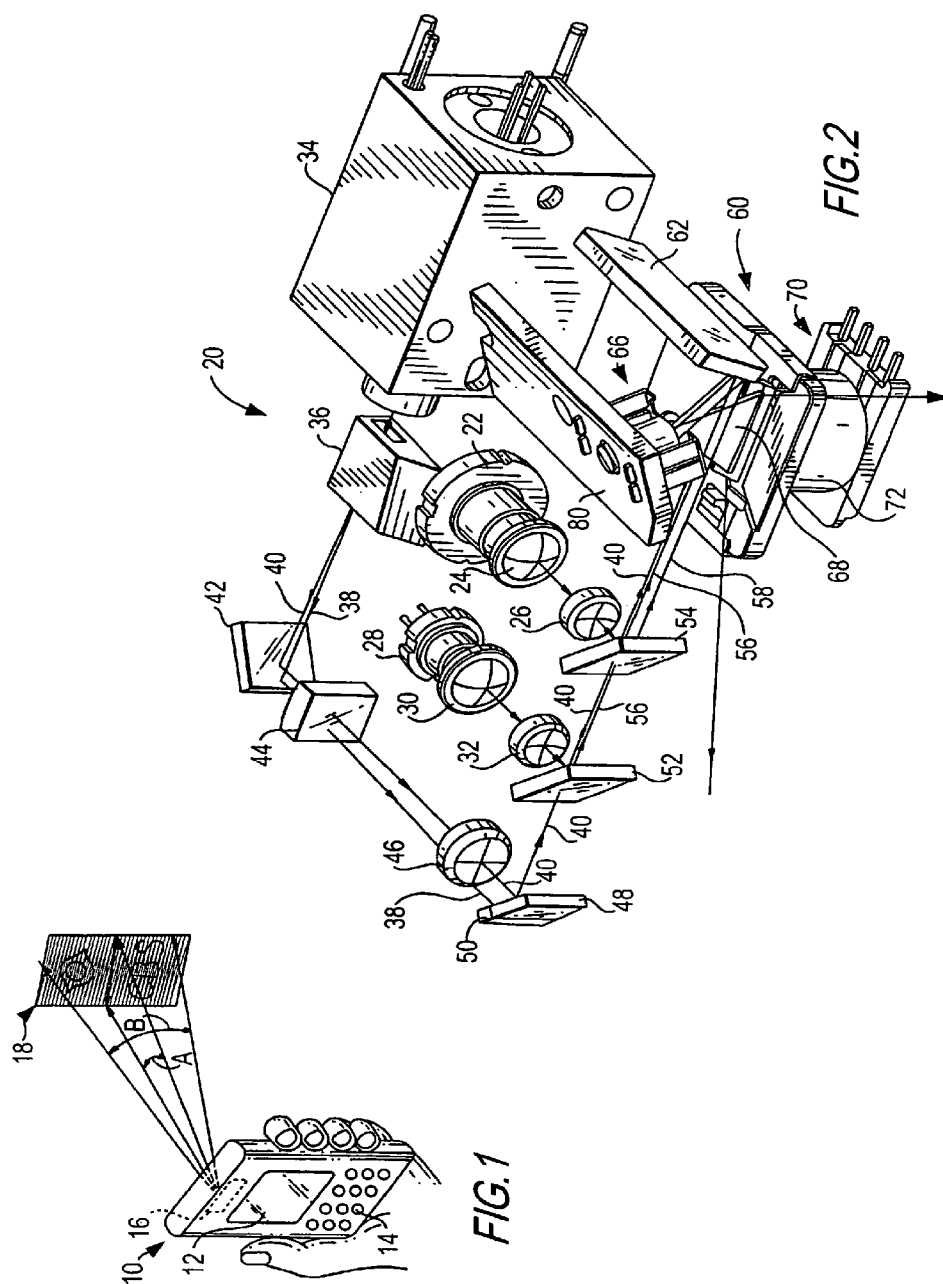
(74) *Attorney, Agent, or Firm* — Kevin D. Wills

(57) **ABSTRACT**

A lightweight, compact image projection module, especially for mounting in a housing having a light-transmissive window, is operative for sweeping a composite laser beam as a pattern of linear scan lines on a planar projection surface and for causing selected pixels arranged along each linear scan line to be illuminated to produce an image of high quality and in color.

**18 Claims, 8 Drawing Sheets**





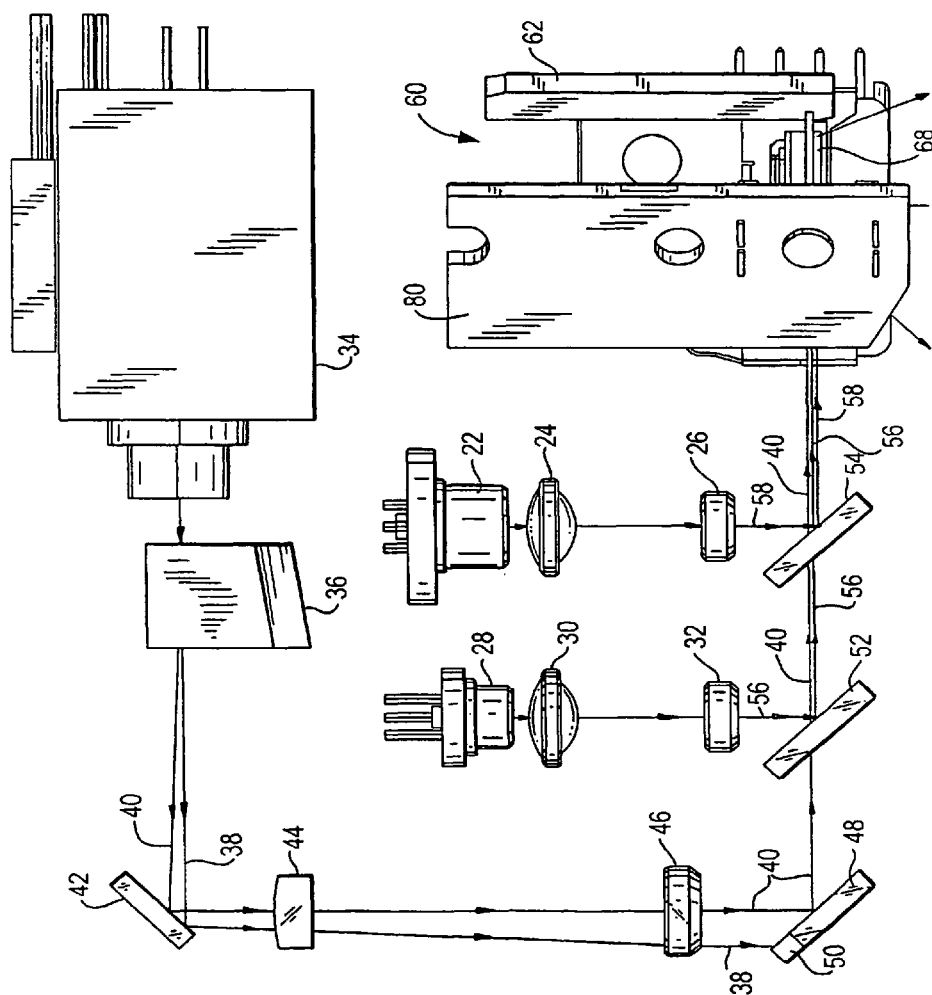


FIG. 3

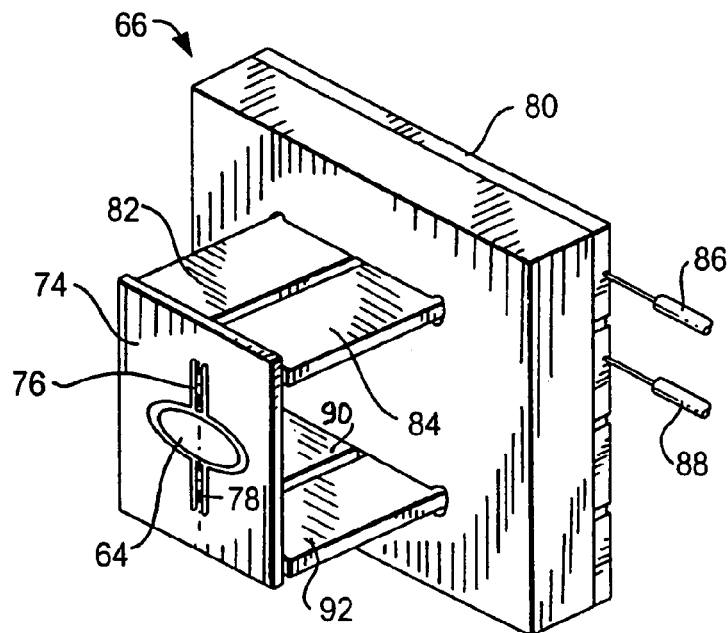


FIG. 4

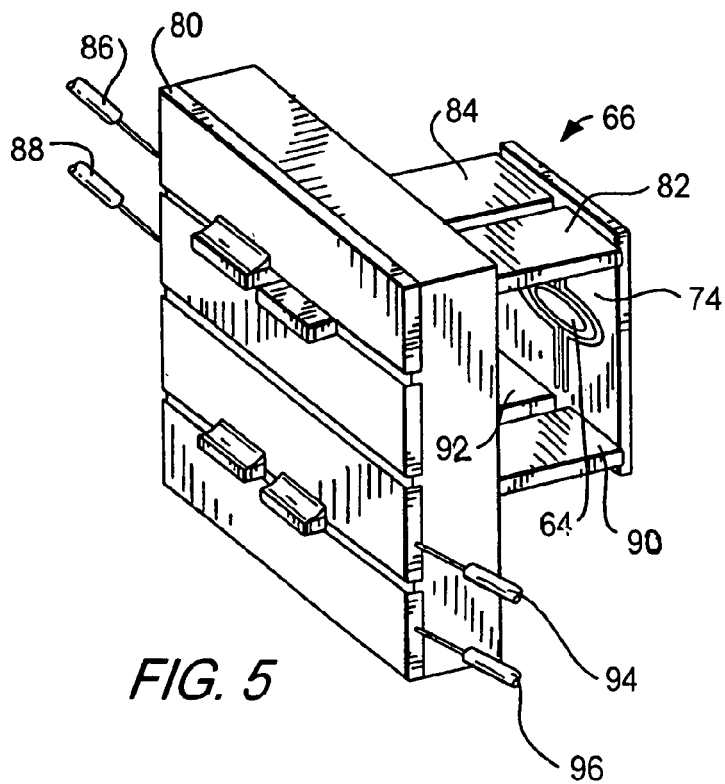


FIG. 5

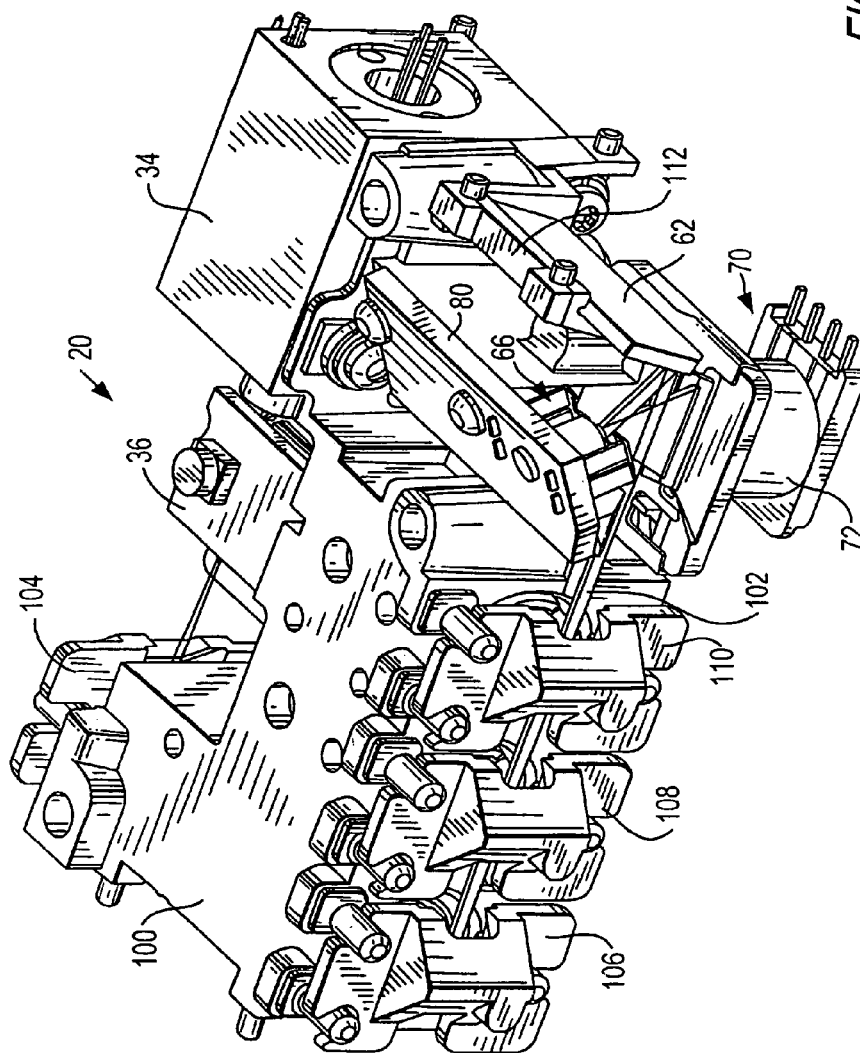


FIG. 6

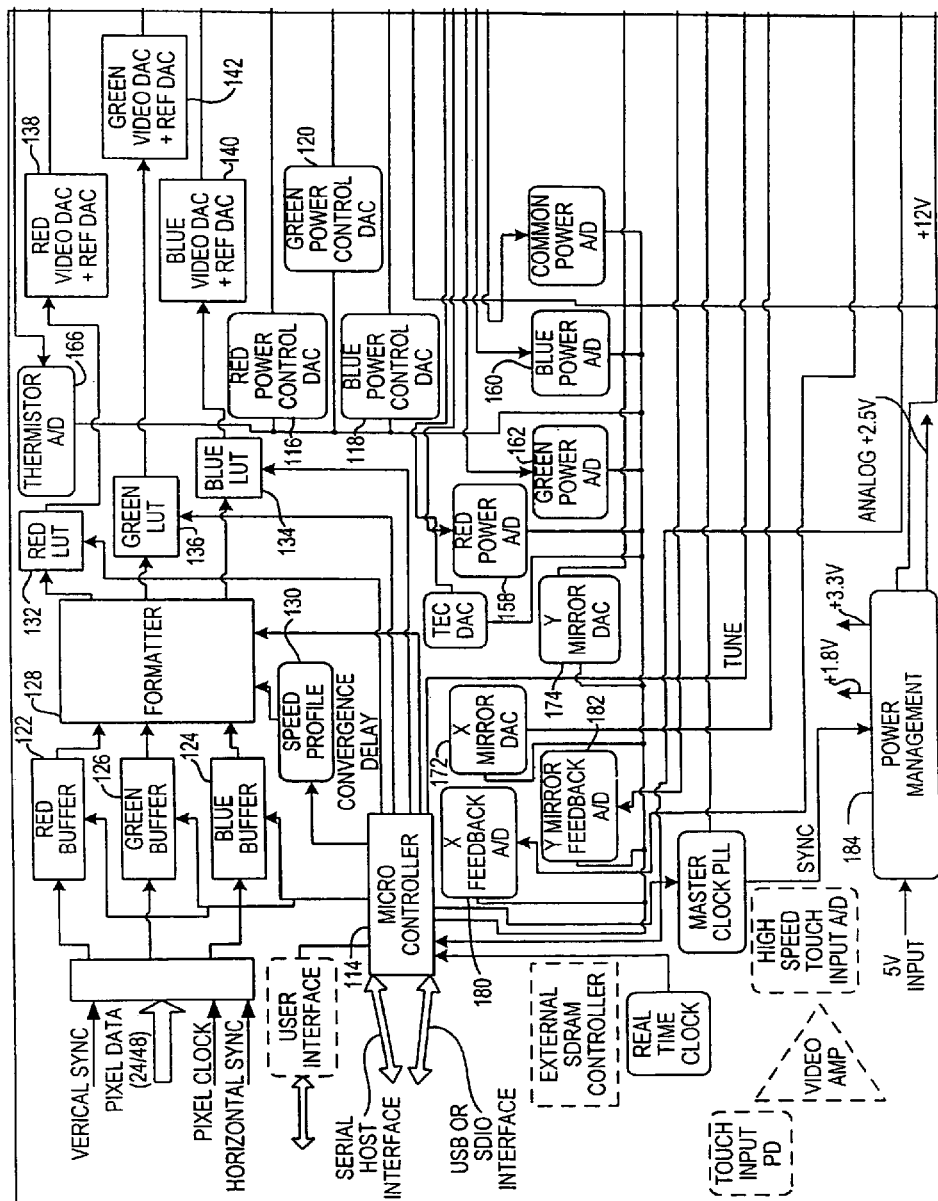


FIG. 7

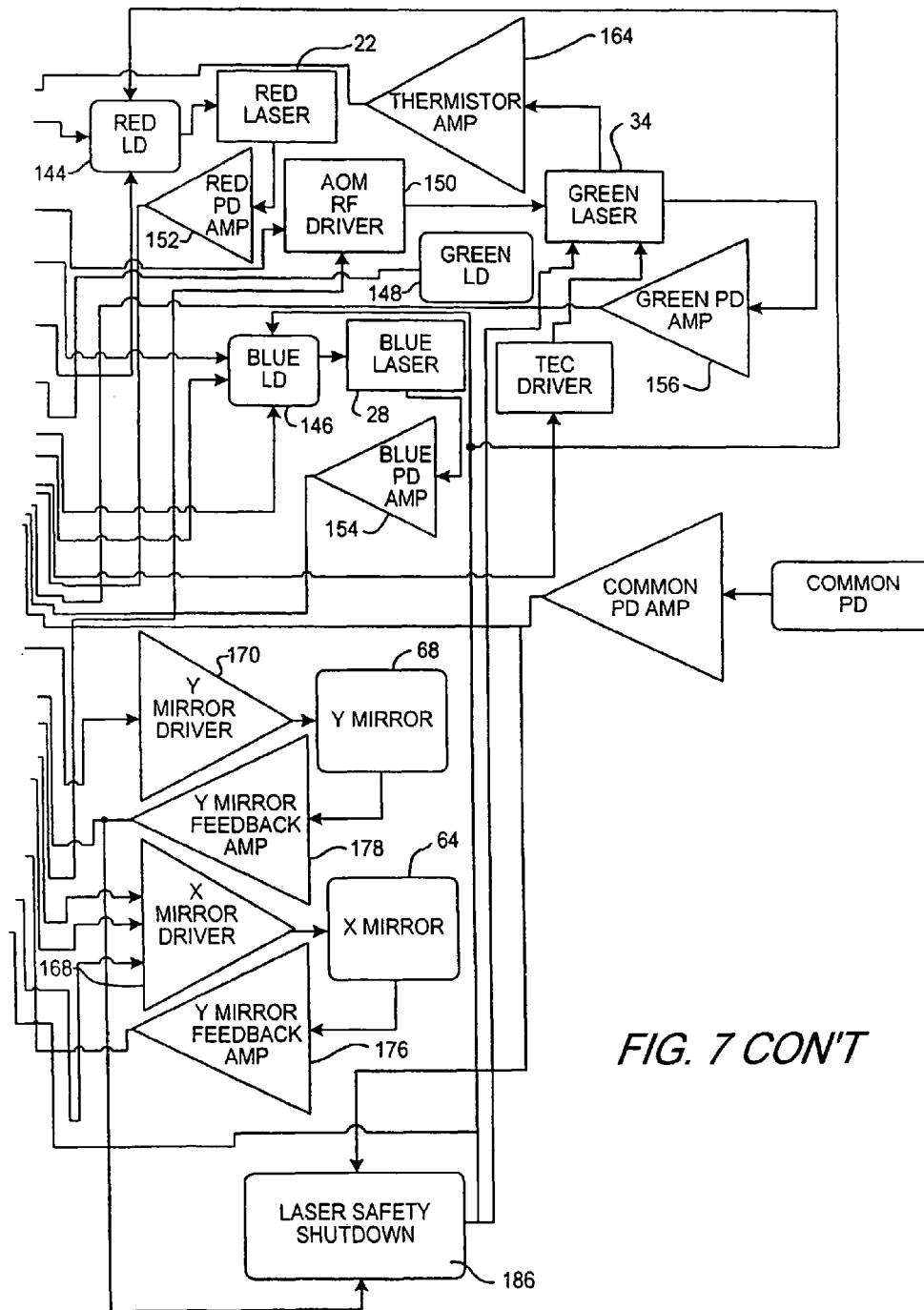
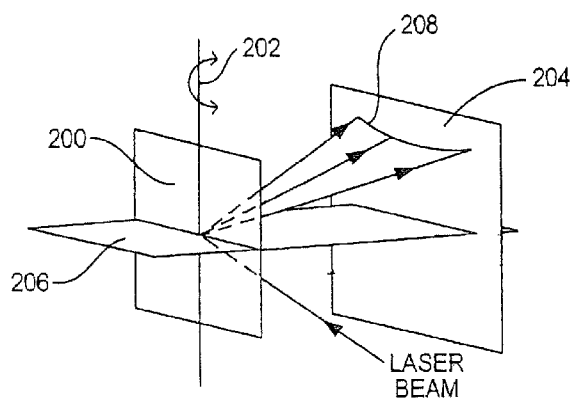
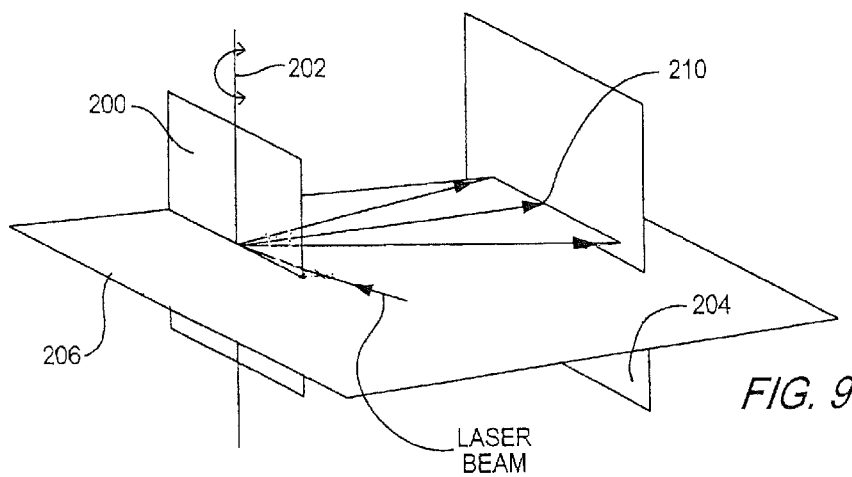


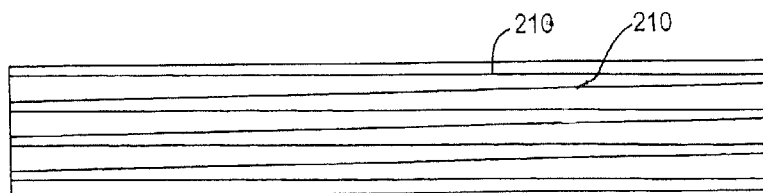
FIG. 7 CON'T



*FIG. 8*  
(PRIOR ART)

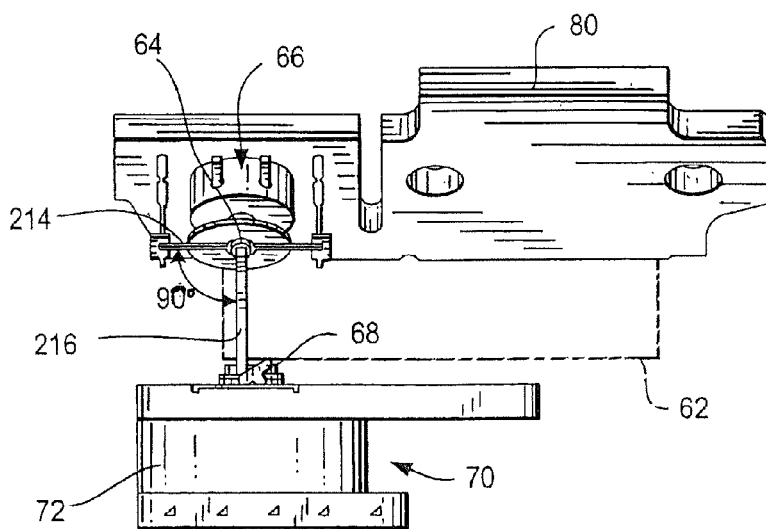
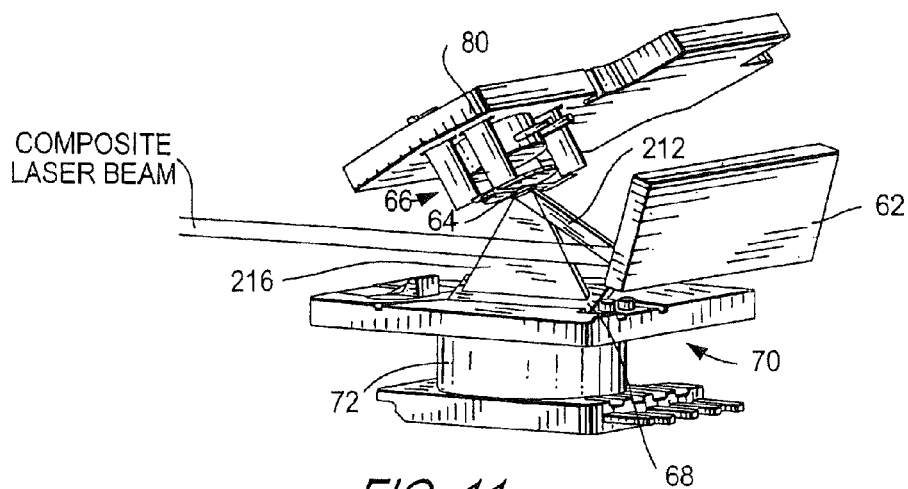


*FIG. 9*



*FIG. 10*





1

## ARRANGEMENT FOR AND METHOD OF PROJECTING AN IMAGE WITH LINEAR SCAN LINES

### CROSS REFERENCE TO RELATED APPLICATIONS

This application is a continuation of U.S. patent application Ser. No. 11/440,815, filed May 25, 2006, which claims priority to U.S. Provisional Patent Application Ser. No. 60/380,806, filed May 15, 2002, and which is a continuation-in-part of U.S. patent application Ser. No. 10/427,528, filed May 1, 2003, which issued as U.S. Pat. No. 7,446,822 on Nov. 4, 2008. All of the above-listed patent applications are incorporated by reference herein in their entirety for all purposes.

### BACKGROUND OF THE INVENTION

#### 1. Field of the Invention

The present invention generally relates to projecting a two-dimensional image of high quality especially in color.

#### 2. Description of the Related Art

It is generally known to project a two-dimensional image on a projection surface based on a pair of scan mirrors which oscillate in mutually orthogonal directions to scan a laser beam over a raster pattern comprised of a plurality of scan lines. However, the known image projection systems project the image with curved scan lines, thereby imparting to the image a distortion which is difficult to correct electronically.

### SUMMARY OF THE INVENTION

#### Objects of the Invention

Accordingly, it is a general object of this invention to provide an image projection arrangement that projects a two-dimensional image, especially in color, of high quality in accordance with the method of this invention.

Another object of this invention is to project the image with linear scan lines in such projection arrangements.

Yet another object of this invention is to reduce, if not eliminate, objectionable distorted images in such projection arrangements.

An additional object is to provide a miniature, compact, lightweight, and portable color image projection module useful in many instruments of different form factors.

#### Features of the Invention

In keeping with these objects and others, which will become apparent hereinafter, one feature of this invention resides, briefly stated, in an image projection arrangement for, and a method of, projecting a two-dimensional image of high quality, especially in color. The arrangement includes a laser assembly for directing a laser beam; a scanner including a scan mirror oscillatable about a scan axis, for sweeping the laser beam as a pattern of scan lines during oscillation of the scan mirror on a planar projection surface at a distance from the laser assembly, each scan line having a number of pixels; and a controller operatively connected to the laser assembly and the scanner, for causing selected pixels to be illuminated, and rendered visible, by the laser beam to produce the image.

In accordance with one aspect of this invention, the laser beam is directed to the scan mirror along an optical path in a plane, which is perpendicular to the scan axis. This enables each of the scan lines on the planar projection surface to be

2

linear, thereby reducing, if not eliminating, the image distortion caused by curved scan lines according to the prior art.

In the preferred embodiment, the laser assembly includes a plurality of lasers for respectively generating a plurality of laser beams of different wavelengths, for example, red, blue and green laser beams, and an optical assembly for focusing and nearly collinearly arranging the laser beams to form the laser beam as a composite beam which is directed to the scan mirror. The scan mirror is operative for sweeping the composite beam along a first linear direction at a first scan rate and over a first scan angle. Another oscillatable scan mirror is operative for sweeping the composite beam along a second direction substantially perpendicular to the first linear direction, and at a second scan rate different from the first scan rate, and at a second scan angle different from the first scan angle. At least one of the scan mirrors is oscillated by an inertial drive.

It is advantageous if a support is provided for supporting the laser assembly and the scanner. Preferably, the optical assembly includes a fold mirror mounted on the support at an angle of inclination for directing the composite laser beam along the plane perpendicular to the scan axis.

The controller includes means for energizing the laser assembly to illuminate the selected pixels, and for deenergizing the laser assembly to non-illuminate pixels other than the selected pixels. The controller also includes means for effectively aligning the laser beams collinearly by delaying turning on and off the pixels of each of the laser beams relative to each other.

The support, lasers, scanner, controller and optical assembly preferably occupy a volume of less than thirty cubic centimeters, thereby constituting a compact module, which is interchangeably mountable in housings of different form factors, including, but not limited to, a pen-shaped, gun-shaped or flashlight-shaped instrument, a personal digital assistant, a pendant, a watch, a computer, and, in short, any shape due to its compact and miniature size. The projected image can be used for advertising or signage purposes, or for a television or computer monitor screen, and, in short, for any purpose desiring something to be displayed.

The novel features which are considered as characteristic of the invention are set forth in particular in the appended claims. The invention itself, however, both as to its construction and its method of operation, together with additional objects and advantages thereof, will be best understood from the following description of specific embodiments when read in connection with the accompanying drawings.

### BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a perspective view of a hand-held instrument projecting an image at a working distance therefrom;

FIG. 2 is an enlarged, overhead, perspective view of an image projection arrangement in accordance with this invention for installation in the instrument of FIG. 1;

FIG. 3 is a top plan view of the arrangement of FIG. 2;

FIG. 4 is a perspective front view of an inertial drive for use in the arrangement of FIG. 2;

FIG. 5 is a perspective rear view of the inertial drive of FIG. 4;

FIG. 6 is a perspective view of a practical implementation of the arrangement of FIG. 2;

FIG. 7 is an electrical schematic block diagram depicting operation of the arrangement of FIG. 2;

FIG. 8 is a perspective schematic view of part of an image projection arrangement for projecting an image with undesirable curved scan lines in accordance with the prior art;

3

FIG. 9 is a perspective schematic view of part of an image projection arrangement for projecting an image with linear scan lines in accordance with this invention;

FIG. 10 is an enlarged front elevational view of a raster pattern with linear scan lines projected by the arrangement of FIG. 9;

FIG. 11 is a perspective, enlarged view of part of the image projection arrangement of FIG. 2, depicting part of the optical path of the laser beam; and

FIG. 12 is an enlarged, side elevational view of FIG. 11, again depicting the optical path of the laser beam.

#### DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

Reference numeral 10 in FIG. 1 generally identifies a hand-held instrument, for example, a personal digital assistant, in which a lightweight, compact, image projection arrangement 20, as shown in FIG. 2, is mounted and operative for projecting a two-dimensional color image on a generally planar projection surface at a variable distance from the instrument. By way of example, an image 18 is situated within a working range of distances relative to the instrument 10.

As shown in FIG. 1, the image 18 extends over an optical horizontal scan angle A extending along the horizontal direction, and over an optical vertical scan angle B extending along the vertical direction, of the image. As described below, the image is comprised of illuminated and non-illuminated pixels on a raster pattern of scan lines swept by a scanner in the arrangement 20.

The parallelepiped shape of the instrument 10 represents just one form factor of a housing in which the arrangement 20 may be implemented. The instrument can be shaped with many different form factors, such as a pen, a cellular telephone, a clamshell or a wristwatch.

In the preferred embodiment, the arrangement 20 measures less than about 30 cubic centimeters in volume. This compact, miniature size allows the arrangement 20 to be mounted in housings of many diverse shapes, large or small, portable or stationary, including some having an on-board display 12, a keypad 14, and a window 16 through which the image is projected.

Referring to FIGS. 2 and 3, the arrangement 20 includes a solid-state, preferably a semiconductor laser 22 which, when energized, emits a bright red laser beam at about 635-655 nanometers. Lens 24 is a bi-convex lens having a positive focal length and is operative for collecting virtually all the energy in the red beam and for producing a diffraction-limited beam. Lens 26 is a concave lens having a negative focal length. Lenses 24, 26 are held by non-illustrated respective lens holders apart on a support (not illustrated in FIG. 2 for clarity) inside the instrument 10. The lenses 24, 26 shape the red beam profile over the working distance.

Another solid-state, semiconductor laser 28 is mounted on the support and, when energized, emits a diffraction-limited blue laser beam at about 430-480 nanometers. Another bi-convex lens 30 and a concave lens 32 are employed to shape the blue beam profile in a manner analogous to lenses 24, 26.

A green laser beam having a wavelength on the order of 530 nanometers is generated not by a semiconductor laser, but instead by a green module 34 having an infrared diode-pumped YAG crystal laser whose output beam at 1060 nanometers. A non-linear frequency doubling crystal is included in the infrared laser cavity between two laser mirrors. Since the infrared laser power inside the cavity is much larger than the power coupled outside the cavity, the frequency doubler is more efficient in generating the double frequency green light inside the cavity. The output mirror of the laser is reflective to the 1060 nm infrared radiation, and transmissive to the doubled 530 nm green laser beam. Since the correct operation of the solid-state laser and frequency doubler require precise temperature control, a semiconductor device relying on the Peltier effect is used to control the temperature of the green laser module. The thermo-electric cooler can either heat or cool the device depending on the polarity of the applied current. A thermistor is part of the green laser module in order to monitor its temperature. The readout from the thermistor is fed to a controller, which adjusts the control current to the thermoelectric cooler accordingly.

4

As explained below, the lasers are pulsed in operation at frequencies on the order of 100 MHz. The red and blue semiconductor lasers 22, 28 can be pulsed at such high frequencies, but the currently available green solid-state lasers cannot. As a result, the green laser beam exiting the green module 34 is pulsed with an acousto-optical modulator 36 which creates an acoustic traveling wave inside a crystal for diffracting the green beam. The modulator 36, however, produces a zero-order, non-diffracted beam 38 and a first-order, pulsed, diffracted beam 40. The beams 38, 40 diverge from each other and, in order to separate them to eliminate the undesirable zero-order beam 38, the beams 38, 40 are routed along a long, folded path having a folding mirror 42. Alternatively, an electro-optical modulator can be used either externally or internally to the green laser module to pulse the green laser beam. Other possible ways to modulate the green laser beam include electro-absorption modulation, or Mach-Zender interferometer. The beams 38, 40 are routed through positive and negative lenses 44, 46. However, only the diffracted green beam 40 is allowed to impinge upon, and reflect from, the folding mirror 48. The non-diffracted beam 38 is absorbed by an absorber 50, preferably mounted on the mirror 48.

The arrangement includes a pair of dichroic filters 52, 54 arranged to make the green, blue and red beams as collinear as possible before reaching a scanning assembly 60. Filter 52 allows the green beam 40 to pass therethrough, but the blue beam 56 from the blue laser 28 is reflected by the interference effect. Filter 54 allows the green and blue beams 40, 56 to pass therethrough, but the red beam 58 from the red laser 22 is reflected by the interference effect.

The nearly collinear beams 40, 56, 58 are directed to, and reflected off, a stationary fold mirror 62. The scanning assembly 60 includes a first scan mirror 64 oscillatable by an inertial drive 66 (shown in isolation in FIGS. 4-5) at a first scan rate to sweep the laser beams reflected off the fold mirror 62 over the first horizontal scan angle A, and a second scan mirror 68 oscillatable by an electromagnetic drive 70 at a second scan rate to sweep the laser beams reflected off the first scan mirror 64 over the second vertical scan angle B. In a variant construction, the scan mirrors 64, 68 can be replaced by a single two-axis mirror.

The inertial drive 66 is a high-speed, low electrical power-consuming component. Details of the inertial drive can be found in U.S. patent application Ser. No. 10/387,878, filed Mar. 13, 2003, assigned to the same assignee as the instant application, and incorporated herein by reference thereto. The use of the inertial drive reduces power consumption of the scanning assembly 60 to less than one watt and, in the case of projecting a color image, as described below, to less than ten watts.

The drive 66 includes a movable frame 74 for supporting the scan mirror 64 by means of a hinge that includes a pair of

5

collinear hinge portions **76**, **78** extending along a hinge axis and connected between opposite regions of the scan mirror **64** and opposite regions of the frame. The frame **74** need not surround the scan mirror **64**, as shown.

The frame, hinge portions and scan mirror are fabricated of a one-piece, generally planar, silicon substrate, which is approximately 150 $\mu$  thick. The silicon is etched to form omega-shaped slots having upper parallel slot sections, lower parallel slot sections, and U-shaped central slot sections. The scan mirror **64** preferably has an oval shape and is free to move in the slot sections. In the preferred embodiment, the dimensions along the axes of the oval-shaped scan mirror measure 749 $\mu$ ×1600 $\mu$ . Each hinge portion measures 27 $\mu$  in width and 1130 $\mu$  in length. The frame has a rectangular shape measuring 3100 $\mu$  in width and 4600 $\mu$  in length.

The inertial drive is mounted on a generally planar, printed circuit board **80** and is operative for directly moving the frame and, by inertia, for indirectly oscillating the scan mirror **64** about the hinge axis. One embodiment of the inertial drive includes a pair of piezoelectric transducers **82**, **84** extending perpendicularly of the board **80** and into contact with spaced apart portions of the frame **74** at either side of hinge portion **76**. An adhesive may be used to insure a permanent contact between one end of each transducer and each frame portion. The opposite end of each transducer projects out of the rear of the board **80** and is electrically connected by wires **86**, **88** to a periodic alternating voltage source (not shown).

In use, the periodic signal applies a periodic drive voltage to each transducer and causes the respective transducer to alternately extend and contract in length. When transducer **82** extends, transducer **84** contracts, and vice versa, thereby simultaneously pushing and pulling the spaced apart frame portions and causing the frame to twist about the hinge axis. The drive voltage has a frequency corresponding to the resonant frequency of the scan mirror. The scan mirror is moved from its initial rest position until it also oscillates about the hinge axis at the resonant frequency. In a preferred embodiment, the frame and the scan mirror are about 150 $\mu$  thick, and the scan mirror has a high Q factor. A movement on the order of 1 $\mu$  by each transducer can cause oscillation of the scan mirror at scan angles in excess of 15°.

Another pair of piezoelectric transducers **90**, **92** extends perpendicularly of the board **80** and into permanent contact with spaced apart portions of the frame **74** at either side of hinge portion **78**. Transducers **90**, **92** serve as feedback devices to monitor the oscillating movement of the frame and to generate and conduct electrical feedback signals along wires **94**, **96** to a feedback control circuit (not shown).

Although light can reflect off an outer surface of the scan mirror, it is desirable to coat the surface of the mirror **64** with a specular coating made of gold, silver, aluminum, or a specially designed highly reflective dielectric coating.

The electromagnetic drive **70** includes a permanent magnet jointly mounted on and behind the second scan mirror **68**, and an electromagnetic coil **72** operative for generating a periodic magnetic field in response to receiving a periodic drive signal. The coil **72** is adjacent the magnet so that the periodic field magnetically interacts with the permanent field of the magnet and causes the magnet and, in turn, the second scan mirror **68** to oscillate.

The inertial drive **66** oscillates the scan mirror **64** at a high speed at a scan rate preferably greater than 5 kHz and, more particularly, on the order of 18 kHz or more. This high scan rate is at an inaudible frequency, thereby minimizing noise and vibration. The electromagnetic drive **70** oscillates the scan mirror **68** at a slower scan rate on the order of 40 Hz

6

which is fast enough to allow the image to persist on a human eye retina without excessive flicker.

The faster mirror **64** sweeps a generally horizontal scan line, and the slower mirror **68** sweeps the generally horizontal scan line vertically, thereby creating a raster pattern which is a grid or sequence of roughly parallel scan lines from which the image is constructed. Each scan line has a number of pixels. The image resolution is preferably XGA quality of 1024×768 pixels. Over a limited working range, a high-definition television standard, denoted 720p, 1270×720 pixels, can be obtained. In some applications, a one-half VGA quality of 320×480 pixels, or one-fourth VGA quality of 320×240 pixels, is sufficient. At minimum, a resolution of 160×160 pixels is desired.

The roles of the mirrors **64**, **68** could be reversed so that mirror **68** is the faster, and mirror **64** is the slower. Mirror **64** can also be designed to sweep the vertical scan line, in which event, mirror **68** would sweep the horizontal scan line. Also, the inertial drive can be used to drive the mirror **68**. Indeed, either mirror can be driven by an electromechanical, electrical, mechanical, electrostatic, magnetic, or electromagnetic drive.

The slow-mirror is operated in a constant velocity sweep-mode during which time the image is displayed. During the mirror's return, the mirror is swept back into the initial position at its natural frequency, which is significantly higher. During the mirror's return trip, the lasers can be powered down in order to reduce the power consumption of the device.

FIG. 6 is a practical implementation of the arrangement **20** in the same perspective as that of FIG. 2. The aforementioned components are mounted on a support, which includes a top cover **100** and a support plate **102**. Holders **104**, **106**, **108**, **110**, **112** respectively hold folding mirrors **42**, **48**, filters **52**, **54** and fold mirror **62** in mutual alignment. Each holder has a plurality of positioning slots for receiving positioning posts stationarily mounted on the support. Thus, the mirrors and filters are correctly positioned. As shown, there are three posts, thereby permitting two angular adjustments and one lateral adjustment. Each holder can be glued in its final position.

The image is constructed by selective illumination of the pixels in one or more of the scan lines. As described below in greater detail with reference to FIG. 7, a controller **114** causes selected pixels in the raster pattern to be illuminated, and rendered visible, by the three laser beams. For example, red, blue and green power controllers **116**, **118**, **120** respectively conduct electrical currents to the red, blue and green lasers **22**, **28**, **34** to energize the latter to emit respective light beams at each selected pixel, and do not conduct electrical currents to the red, blue and green lasers to deenergize the latter to non-illuminate the other non-selected pixels. The resulting pattern of illuminated and non-illuminated pixels comprises the image, which can be any display of human- or machine-readable information or graphic.

Referring to FIG. 1, the raster pattern is shown in an enlarged view. Starting at an end point, the laser beams are swept by the inertial drive along the generally horizontal direction at the horizontal scan rate to an opposite end point to form a scan line. Thereupon, the laser beams are swept by the electromagnetic drive **70** along the vertical direction at the vertical scan rate to another end point to form a second scan line. The formation of successive scan lines proceeds in the same manner.

The image is created in the raster pattern by energizing or pulsing the lasers on and off at selected times under control of the microprocessor **114** or control circuit by operation of the power controllers **116**, **118**, **120**. The lasers produce visible

light and are turned on only when a pixel in the desired image is desired to be seen. The color of each pixel is determined by one or more of the colors of the beams. Any color in the visible light spectrum can be formed by the selective superimposition of one or more of the red, blue, and green lasers. The raster pattern is a grid made of multiple pixels on each line, and of multiple lines. The image is a bit-map of selected pixels. Every letter or number, any graphical design or logo, and even machine-readable bar code symbols, can be formed as a bit-mapped image.

As shown in FIG. 7, an incoming video signal having vertical and horizontal synchronization data, as well as pixel and clock data, is sent to red, blue and green buffers 122, 124, 126 under control of the microprocessor 114. The storage of one full VGA frame requires many kilobytes, and it would be desirable to have enough memory in the buffers for two full frames to enable one frame to be written, while another frame is being processed and projected. The buffered data is sent to a formatter 128 under control of a speed profiler 130 and to red, blue and green look up tables (LUTs) 132, 134, 136 to correct inherent internal distortions caused by scanning, as well as geometrical distortions caused by the angle of the display of the projected image. The resulting red, blue and green digital signals are converted to red, blue and green analog signals by digital to analog converters (DACs) 138, 140, 142. The red and blue analog signals are fed to red and blue laser drivers (LDs) 144, 146 which are also connected to the red and blue power controllers 116, 118. The green analog signal is fed to an acousto-optical module (AOM) radio frequency (RF) driver 150 and, in turn, to the green laser 34 which is also connected to a green LD 148 and to the green power controller 120.

Feedback controls are also shown in FIG. 7, including red, blue and green photodiode amplifiers 152, 154, 156 connected to red, blue and green analog-to-digital (A/D) converters 158, 160, 162 and, in turn, to the microprocessor 114. Heat is monitored by a thermistor amplifier 164 connected to an A/D converter 166 and, in turn, to the microprocessor.

The scan mirrors 64, 68 are driven by drivers 168, 170 which are fed analog drive signals from DACs 172, 174 which are, in turn, connected to the microprocessor. Feedback amplifiers 176, 178 detect the position of the scan mirrors 64, 68, and are connected to feedback A/Ds 180, 182 and, in turn, to the microprocessor.

A power management circuit 184 is operative to minimize power while allowing fast on-times, preferably by keeping the green laser on all the time, and by keeping the current of the red and blue lasers just below the lasing threshold.

A laser safety shut down circuit 186 is operative to shut the lasers off if either of the scan mirrors 64, 68 is detected as being out of position.

Turning now to FIG. 8, a scan mirror 200 is depicted as being oscillatable about a scan axis 202. A generally planar projection surface 204 is depicted at a distance from the scan mirror. Also shown is a plane 206 perpendicular to the scan axis 202. In the prior art, an incoming laser beam is situated above or below the plane 206 and, as a result, the laser beam is swept as a curved scan line 208 on the projection surface 204. An image comprised of a plurality of such curved scan lines spaced generally apart along the scan axis 202 will be distorted and it is difficult to electronically correct for such distortion.

FIG. 9 is analogous to FIG. 8, and like parts are identified with like reference numerals. In the invention of FIG. 9, the incoming laser beam is directed along an optical path in the plane 206 that is perpendicular to the scan axis 202. As a result, the laser beam is swept as a linear scan line 210 on the

projection surface 204. An image comprised of a plurality of such linear scan lines spaced generally apart along the scan axis 202 will not be distorted. FIG. 10 depicts a plurality of the linear scan lines 210, each scan line being tilted as a result of scanning by another scan mirror, but not curved.

FIGS. 11-12 depict the path of the incoming composite laser beam among the fold mirror 62, the fast scan mirror 64 of the drive 66, and the slow scan mirror 68 of the drive 70. The composite laser beam 40, 56, 58 is directed to the inclined fold mirror 62, which is preferably mounted on the support at an angle of inclination of 15° from the vertical, for reflection therefrom as a sub-beam 212 (see FIG. 11) to the fast scan mirror 64. As best seen in FIG. 12, the fast scan mirror 64 oscillates about a scan axis 214, and is preferably mounted on the support at an angle of inclination of 30° from the horizontal. The sub-beam 212 is directed in a plane perpendicular to the scan axis 214 for reflection from the fast scan mirror 64 as a sub-beam 216 to the slow scan mirror 68. The projection of the sub-beam 216 on the slow scan mirror 68 is a straight, uncurved line. The sub-beam 216 is reflected from the slow scan mirror 68 as a raster pattern of linear scan lines (see FIG. 10). The slow scan mirror 68 is oscillatable about a scan axis that is generally parallel to the scan axis 214, and is preferably mounted on the support at an angle of inclination of 33.75° from the horizontal as seen in the side view of FIG. 12.

If a single two-axis mirror is employed to replace the pair of fast and slow scan mirrors, curved scan lines will result, even if the incoming laser beam lies in the plane perpendicular to one of the scan axes, because, at any moment, the one scan axis is always rotating in the orthogonal direction (along the slow scan direction). Hence, in that event, the invention proposes rotating the fold mirror synchronously with the slow scan mirror.

It will be understood that each of the elements described above, or two or more together, also may find a useful application in other types of constructions differing from the types described above.

While the invention has been illustrated and described as embodied in an arrangement for and a method of projecting an image with linear scan lines, it is not intended to be limited to the details shown, since various modifications and structural changes may be made without departing in any way from the spirit of the present invention.

Without further analysis, the foregoing will so fully reveal the gist of the present invention that others can, by applying current knowledge, readily adapt it for various applications without omitting features that, from the standpoint of prior art, fairly constitute essential characteristics of the generic or specific aspects of this invention and, therefore, such adaptations should and are intended to be comprehended within the meaning and range of equivalence of the following claims.

We claim:

1. An apparatus comprising:

a first mirror having a first axis upon which the first mirror can move;

an optical component positioned to provide laser light to the first mirror on a light path perpendicular to the first axis; and

a second mirror having a second axis upon which the second mirror can move, the second mirror positioned to receive light reflected from the first mirror on a straight line parallel to the second axis.

2. The apparatus of claim 1 wherein the optical component comprises a fold mirror.

3. The apparatus of claim 1 further comprising an inertial drive mechanism to cause the first mirror to oscillate on the first axis.

9

4. The apparatus of claim 1 wherein the second mirror moves responsive to a drive system.

5. The apparatus of claim 4 wherein the drive system comprises an electromagnetic drive system.

6. The apparatus of claim 4 wherein the drive system comprises an electrostatic drive system.

7. An image projection arrangement comprising:

at least one laser light source to provide a laser beam;

a scanning assembly having first mirror oscillatable on a first axis and a second mirror oscillatable on a second axis; and

an optical assembly positioned to direct the laser beam to the first mirror on a light path perpendicular to the first axis.

8. The image projection arrangement of claim 7 wherein the first mirror sweeps the laser beam back and forth at a mechanical resonant frequency.

9. The image projection arrangement of claim 7 wherein the first mirror sweeps at a resonant frequency and the second mirror sweeps at a nonresonant frequency.

10. The image projection arrangement of claim 7 wherein the at least one laser light source comprises a plurality of laser light sources to provide laser beams with differing wavelengths.

11. The image projection arrangement of claim 7 wherein the second mirror moves responsive to an electromagnetic drive system.

10

12. The image projection arrangement of claim 7 wherein the second mirror moves responsive to an electrostatic drive system.

13. A hand-held instrument comprising:

a laser light source to provide a laser beam;

a first mirror oscillatable on a first axis, the first mirror positioned to receive the laser beam on an optical path perpendicular to the first axis; and

a second mirror oscillatable on a second axis, the second mirror positioned to receive the laser beam reflected from the first mirror, the second scan mirror operative to reflect and sweep the laser beam to form a raster pattern.

14. The hand-held instrument of claim 13 wherein the first mirror sweeps at a mechanically resonant frequency.

15. The hand-held instrument of claim 13 wherein the second mirror sweeps at a nonresonant frequency.

16. The hand-held instrument of claim 13 wherein the laser light source comprises a plurality of lasers to provide different color laser beams.

17. The hand-held instrument of claim 13 wherein the handheld instrument comprises a mobile phone.

18. The hand-held instrument of claim 13 wherein the handheld instrument comprises a computer.

\* \* \* \* \*